Analysis and Modeling of Microwave Scattering Data

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LONG-TERM GOALS

Our long-range objective is to detect and understand microwave sea surface signatures produced by a variety of natural and man-made causes.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are to develop and test the multiscale model of microwave backscatter from the ocean to enhance its range of applicability, especially at high incidence angles and during rain.

APPROACH

Our approach is to develop spectral models of short waves on the sea surface for use in the multiscale model that will include effects of bound waves and raindrops. These models are being developed by analyzing previous experimental results, obtained both by us and by others, studying previous theoretical work, conducting new experiments in the University of Miami wind wave tank, and attempting to incorporate the results into the framework of the multiscale model.

WORK COMPLETED

We have analyzed data from several previous experiments during the course of FY 2002. We continue to analyze data on threshold effects in wind wave generation collected in the CCIW wind wave tank in 1996 as well data on short wave modulation by long waves collected in the University of Miami wind wave tank in 2001. We are also using data we collected onboard the R/V Ron Brown in 1999 in our rain effects modeling. Finally, we have spent a lot of time this year analyzing data from the FAIRS experiment that was carried out on FLIP in September and October 2000 near Monterey, CA

The continuing analysis of the CCIW data set is in response to the reviews of the paper we submitted to the Journal of Physical Oceanography. One result of the review was the requirement to split the paper into two parts and we are in the process of doing this (Donelan and Plant, 2002a,b). The paper on the multiscale scattering model that was accepted by the Journal of Geophysical Research last year has not yet been published yet due to the conversion of the journal to electronic publishing (Plant, 2002).

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RESULTS

a. Threshold effects

The reviewers of our paper on threshold and hysteresis effects were quite concerned that the threshold was due to advection of waves down the tank rather than to a true threshold. As a result, we reanalyzed our data on gravity-capillary waves to see if the threshold wind speed depended on fetch when the wind was slowly ramped up as it would if it were due to advective effects. Figure 1 shows the result of this reanalysis.

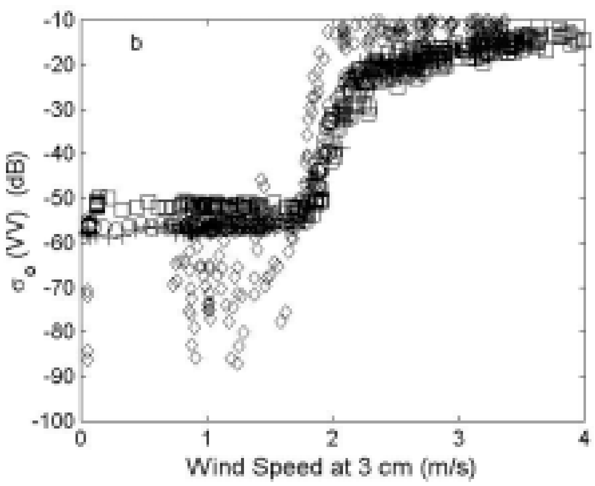

Figure 1. Ku band σ_o at different fetches for a slowly increasing wind versus wind speed at 3 cm. Rate of change of wind speed is 0.3 cm/s/s. Symbols are as follows: squares = 7.4 m fetch; pluses = 10.0 m fetch; circles = 12.4 m fetch; diamonds = spectral densities from laser converted to σ_o(VV), 14.3 m fetch. Radar is at a 45^o incidence angle.

Clearly, the threshold wind speed does not vary with fetch. In fact, the laser data at 14.3 m seem to show a bit lower threshold wind speed than the radar data at shorter fetches. This, of course, is the opposite of the way an advective effect would operate since at the later times when the waves propagate longer fetches, one would expect the wind speed to be higher. Incidentally, this figure shows that the wavelet technique developed by Donelan et al., 1996 when applied to the laser data actually has a lower noise level than the radar.

This threshold effect is now included in the multiscale scattering model for some input wave spectra.

b. Bound wave effects

Our analysis of the FAIRS data set has produced some very interesting results to date. Environmental conditions when the data were collected covered a fairly broad range of wind speeds but were always such that the Ku band antenna at a 70^o incidence angle looked into the wind, wind waves, and swell. We found that spectra collected under these conditions often showed two well-separated peaks as shown in Figure 2.

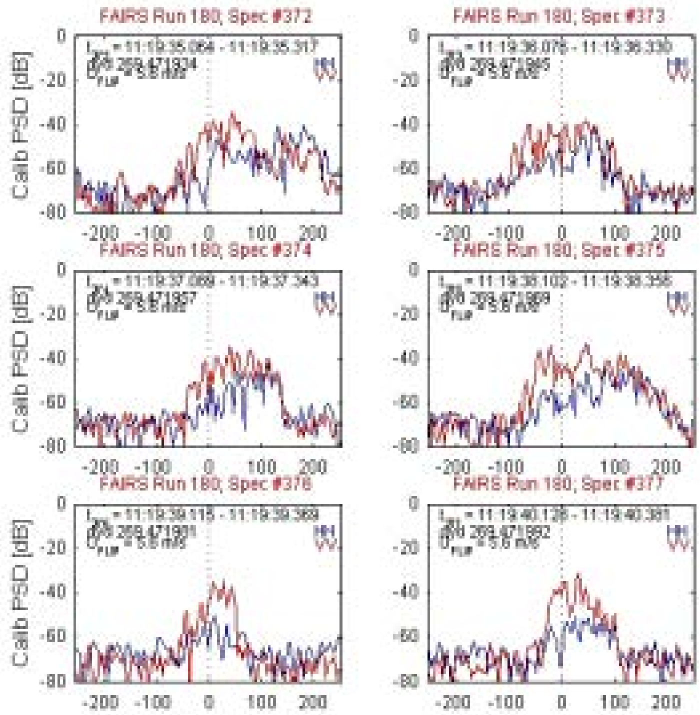

Figure 2. Examples of Ku-band Doppler spectra collected at a 70º incidence angle during FAIRS. Note the dual peaks in Spec #372 and the different maxima in the HH and VV spectra in Spec #375.

This is in agreement with our proposal in 1997 that bound waves having large Doppler shifts are responsible both for differences in HH and VV spectra and for much of the increase in HH cross sections compared to the predictions of standard composite surface theory (Plant, 1997). This proposal was strengthened by comparison with the simultaneous IR data collected during FAIRS. This comparison showed that the microscale breaking waves seen in IR signatures often correlated well with unusual Doppler spectra. Examples are given in the report of Andy Jessup on this CD.

However, when we attempted to test this proposal further by looking at HH and VV cross sections versus wind speed when data having large Doppler shifts were omitted from the analysis, we found that the low Doppler shift data still did not agree with the multiscale model, especially at HH polarization. This indicates that the scatterers responsible for the unexpectedly high HH cross sections do not all have large Doppler shifts. We are presently exploring the possibility that bound, tilted waves are much more ubiquitous on the ocean surface than we had suspected and may be caused by short gravity waves whose phase speed is relatively low.

c. Rain effects

Rain impinging upon the ocean significantly alters the surface wave field and its scattering of microwave radiation. Data collected during the Kwajalein Experiment (KWAJEX) in 1999 was analyzed to determine the effects of rain on Ku band microwave backscatter from the ocean (Contreras et al. 2002). During the experiment, measurements of backscatter were taken at a large range of incidence angles (13^o to 80^o) for both raining and non raining conditions. Figure 3 shows the effect of rain for a wind speed of 5 m s^{-1} and azimuth angles from 0 to 90 degrees. At incidence angles greater

than about 30^o, where Bragg scattering dominates, rain significantly enhances the microwave cross section, with the magnitude of this change increasing with incidence angle. For incidence angles around 20^o to 30^o, there was no notable change in the cross section and at angles less than about 20^o, rain appears to decrease the cross section, however, the statistical uncertainty at these angles is large.

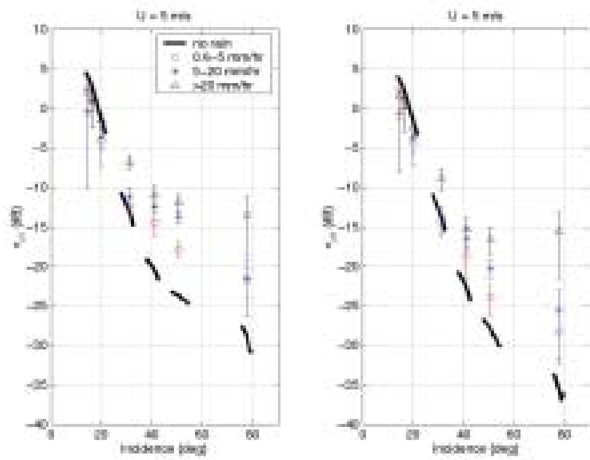

Figure 3. Cross section as a function of incidence angle for no rain (solid black), 0 to 5 mm hr^{1}(red circles), 5 to 20 mm hr^{-1} (blue asterisks), and greater than 20 mm hr^{-1} (black triangles).

We have been attempting to include effects of rain in the multiscale model by modeling the effect of rain of the spectrum of short surface waves. Two primary effects of rain on the water surface are considered: ring wave generation and turbulent damping of short gravity waves. These phenomena alter the background wind wave spectrum. The wind wave spectrum being used is that of Kudryavtsev et al. (1999). This model relies on energy balances to determine the form of the spectrum in different wave number regions, and, therefore, damping by rain-induced turbulence can be added as an eddy viscosity. Ring waves serve to enhance the wave number spectrum. In this treatment, ring waves are simply added to the wind wave spectra mentioned above. Figure 4 is an example of the modeled surface height field. From this the surface height spectrum is calculated. This method extends to higher wave numbers than the model of Bliven et al. (1997).

Our next step is to use this rain-modified spectrum in the multiscale model to predict cross sections during rainfall. The results of the model will then be compared to the data shown above.

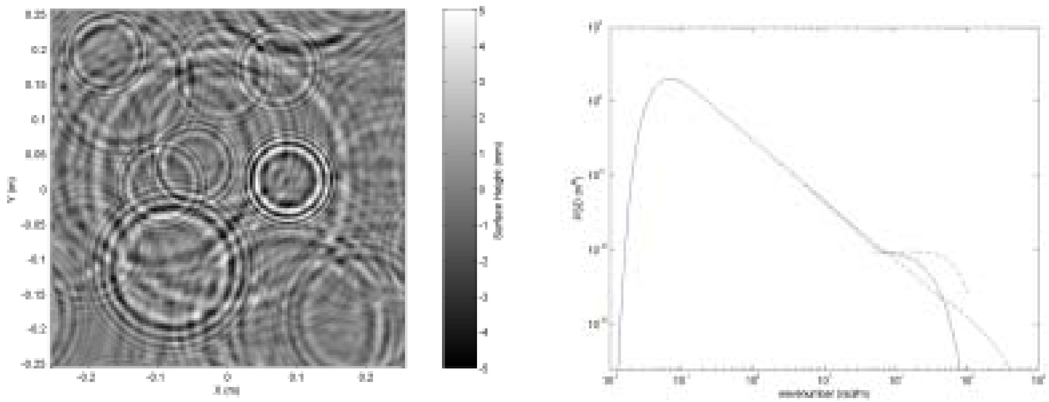

Figure 4 Left - Example of surface height field created when rain (R = 10 mm/hr) strikes a water surface. Right- Surface height spectrum: dashed = wind wave spectrum from Kudryavtsev et al. (1999) with rain damping, solid = the spectrum of Bliven et al. (1997), and dotted = the spectrum of the surface height field shown in on the left.

IMPACT/APPLICATION

Our results shed new light on microwave backscattering from the ocean under a variety of environmental and system conditions. Thus they are applicable to any microwave radar that senses the ocean surface. In particular, they promise to aid our understanding of the imagery of signatures of surface and subsurface vehicles, especially in the higher incidence angle region where bound waves become most important.

TRANSITIONS

The results of this project have not yet been transitioned for operational use.

RELATED PROJECTS

This project is closely related to Andy Jessup's ONR project; FAIRS IR and microwave data are being analyzed jointly with Jessup.

This project is directly related to NASA scatterometers, such as the NSCAT, QuikScat, and SeaWinds. Data collected under this funding have been used in an NSCAT-related project to attempt to develop better model functions and retrieval methods for scatterometers at low wind speeds. Further, the multiscale model is now being used in a NASA study of a physically based model function.

Finally, this project has many parallels with a project run by the Office of the Secretary of Defense to investigate the microwave signatures produced by submarines. The basic understanding of microwave scattering, especially at high incidence angles, produced in this project furthers these attempts to detect submarines.

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